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Vienna, 22 April 2016

Direct radiative effects induced by intense desert dust outbreaks over the broader Mediterranean basin

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COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

MDRAF
MC-IEF-Intra-European Fellowships (IEF)

SEVENTH FRAMEWORK PROGRAMME

MARIE CURIE ACTIONS

Introduction – Aim of the study

- Mediterranean is affected by desert dust outbreaks throughout the year
- Spatiotemporal variability ➔ prevailing atmospheric circulation patterns and dust mobilization in the source areas (Sahara Desert, Middle East)
- Interaction of dust aerosols with the incoming solar (shortwave, SW) and outgoing terrestrial (longwave, LW) radiation ➔ Perturbation of the Earth-Atmosphere system's radiation budget
- Direct, semi-direct and indirect radiative effects
- Impact on atmospheric processes from short- (weather) to long-term (climate) temporal scales
- Direct Radiative Effects (DREs)
  - Scattering and absorption of SW radiation
  - Absorption and re-emission of LW radiation
- Consideration of dust radiative impacts ➔ Improvement of regional model weather forecasts (Pérez et al., 2006)

Calculation of DREs, induced by intense and widespread Mediterranean dust outbreaks, based on regional model simulations ➔ weather forecasts and feedbacks

Observational datasets

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- **Gridded daily satellite retrievals provided at 1ºx1º spatial resolution (Level 3)**
- **MODIS – Terra (Mar. 2000 – Feb. 2013), Collection 051 (C051)**
  - Aerosol Optical Depth at 550nm (AOD_{550nm})
  - Ångström exponent (land → 470 – 660nm, sea → 550-865nm)
  - Fine Fraction
  - Effective radius (over sea)
- **Earth Probe TOMS (2000 – 2004)**
  - Aerosol Index (AI)
- **OMI-Aura (2005 – 2013)**
  - Aerosol Index (AI)

Satellite data

- **Baseline Surface Radiation Network (BSRN)**
  - Downwelling shortwave (SW) and longwave (LW) radiation
  - Sede Boker (South Israel)
- **AERosol RObotic NETwork (AERONET)**
  - Aerosol Optical Depth (AOD) at 550nm
  - Level 2.0
  - Sede Boker (South Israel)

Ground data

NMMB/BSC-Dust regional model

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Model features

- Non-hydrostatic Multiscale Model NMMB (Janjic et al., 2004)
- Arakawa B grid (Arakawa and Lamb, 1977)
- Vertical hybrid σ-pressure coordinate system (Simmons and Burridge, 1981)
- A rotated longitude-latitude coordinated system is used for regional simulations

Physics schemes

- Radiation: RRTM (Mlawer et al., 1997)
- Convection: Betts-Miller-Janjic (BMJ) (Betts, 1986)
- Clouds and microphysics: Ferrier (Ferrier et al., 2002)
- Turbulence: Mellor-Yamada-Janjic (MYJ) (Janjic, 2001)
- Land model: NCEP NOAH (Eck et al., 2003)

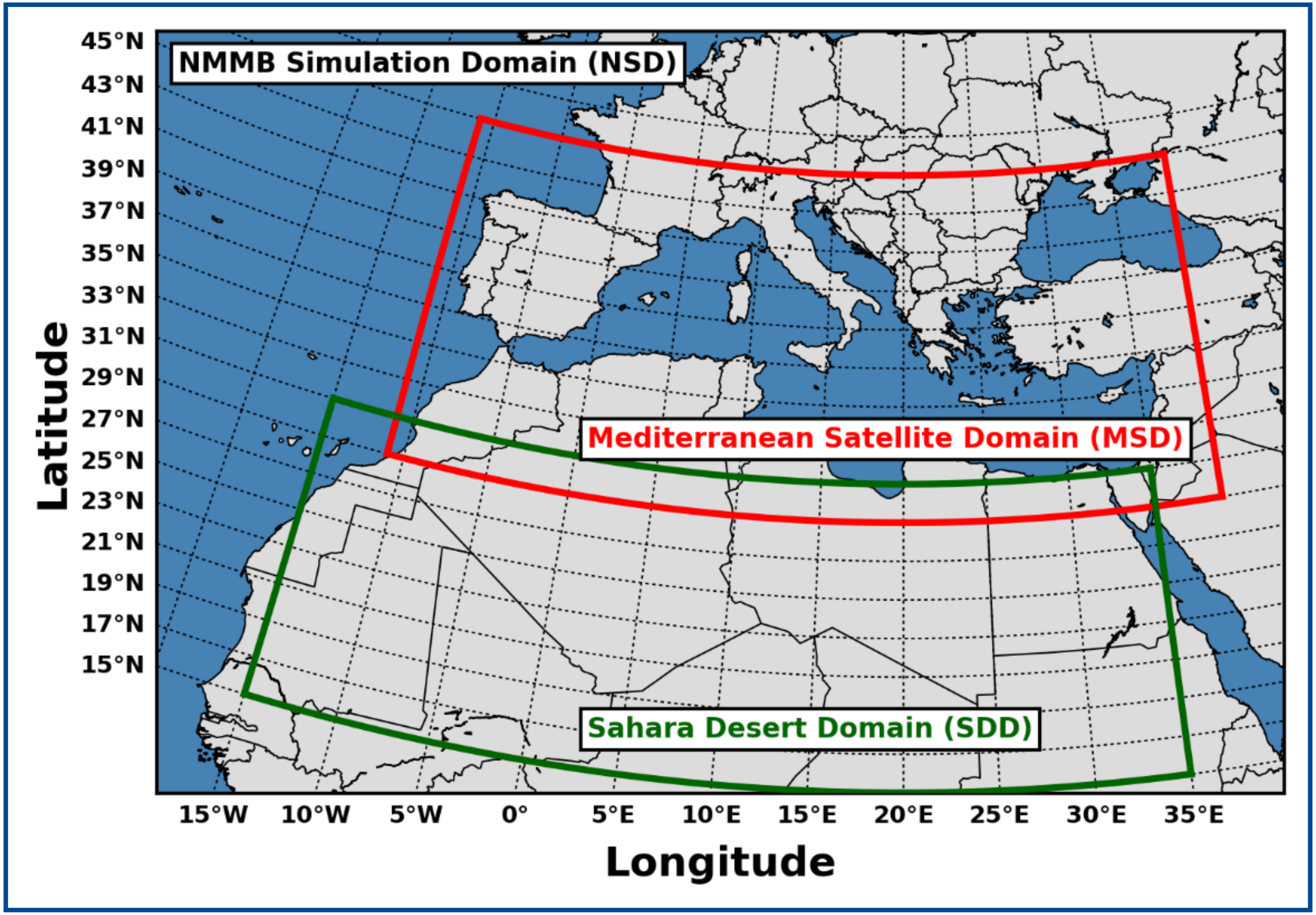
Aerosols

- Dust model: Coupled with the NMMB model (Pérez et al., 2011; Haustein et al., 2012)
- 8 size bins (Tegen and Lacis, 1996; Pérez et al., 2006)
- GOCART (Chin et al., 2002) optical properties (extinction efficiency, SSA, g)
- Other aerosol types: OC, BC, SS, sulfate (2000-2007) – GOCART climatology

Model configuration

- Horizontal: 0.25^o x 0.25^o
- Vertical: 40 σ-pressure levels up to 50hPa
- Initial and 6-hourly boundary conditions: NCEP final analyses (FNL) at 1^o x 1^o
- Forecast range: 84 hours
- Initialization: at 00UTC of the desert dust outbreak day
- Forecast outputs: every 3 hours
- Spin-up period: 10 days (24h reinitialization)

Simulation (NSD) and satellite (MSD) domains



NSD: NMMB/BSC-Dust short-term (84 h) forecasts
MSD: Identification of desert dust outbreaks

Identification of desert dust (DD) episodes at pixel level (MSD domain)

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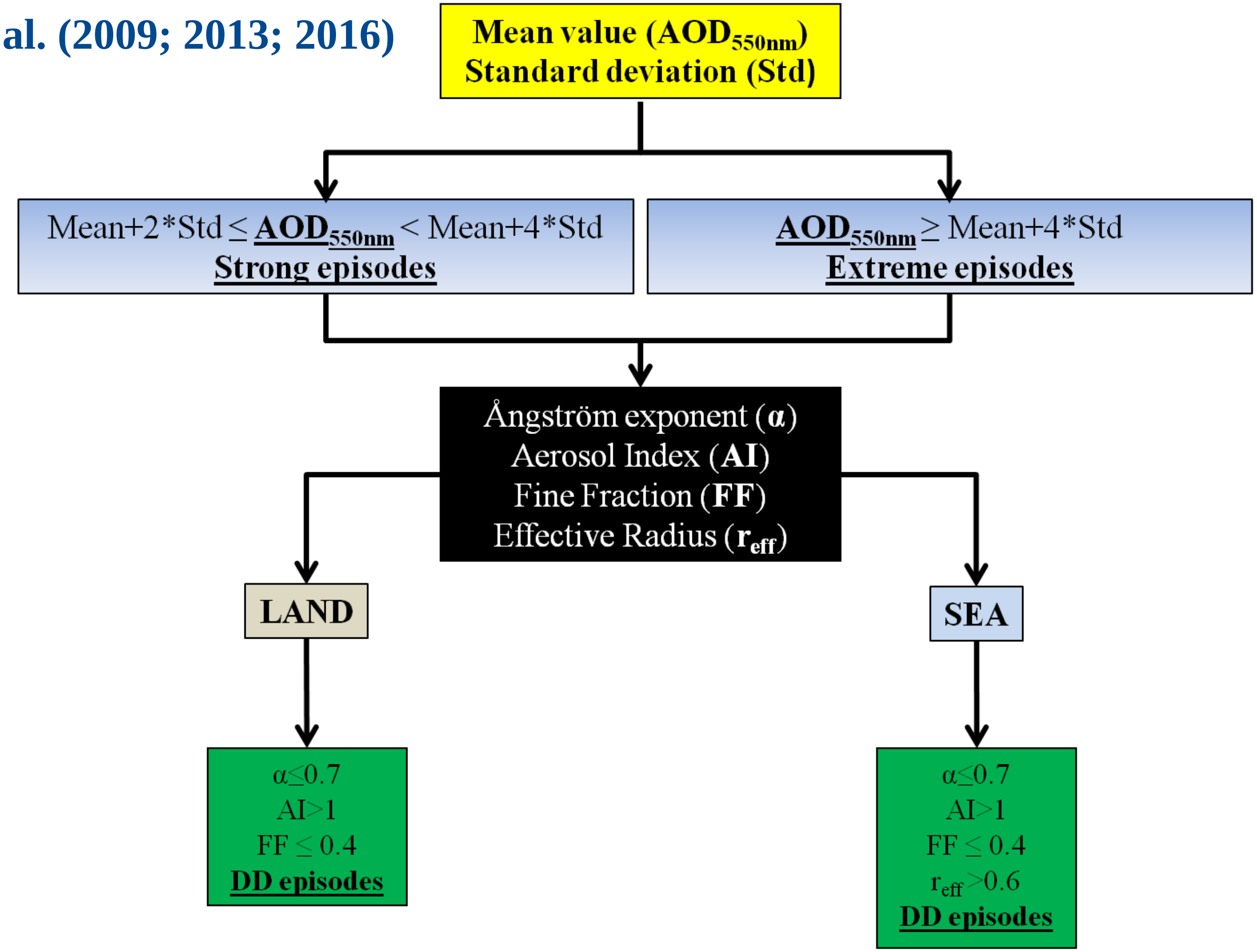
Gkikas et al. (2009; 2013; 2016)



Implementation of the satellite algorithm in each 1º x 1º grid cell

Operation period: 1 March 2000 – 28 February 2013

Selection of desert dust outbreaks at regional level (MSD domain)

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Selection criteria

- Days where at least 30 pixel-level DD episodes (either strong or extreme) have been identified by the satellite algorithm (Gkikas et al., 2012; 2015)
- Calculation of the mean regional AOD considering only pixels undergoing a DD episode
- Ranking of days based on dust outbreaks' intensity (MODIS-Terra regional AOD)
- 20 widespread and intense Mediterranean desert dust outbreaks are analyzed

Statistics

	Dust outbreaks	Percentage (%)	MSD Sector
Winter	5	25%	Eastern – Central
Spring	11	55%	Central – Eastern
Summer	4	20%	Western
Autumn	0	0%	-
Total	20	100%	

Number of DD episodes: 30 (28/7/2005) – 85 (31/7/2001)
Intensity of dust outbreaks: 0.74 (31/7/2001) – 2.96 (2/3/2005)

Intense dust outbreaks over the broader Mediterranean basin

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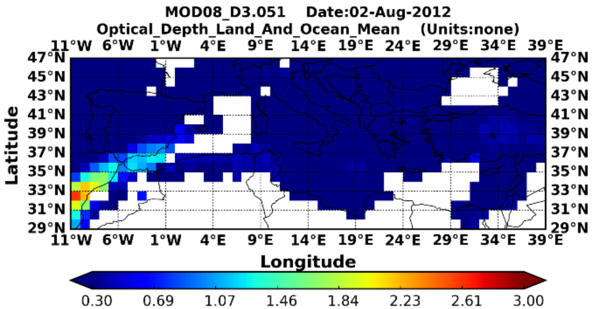
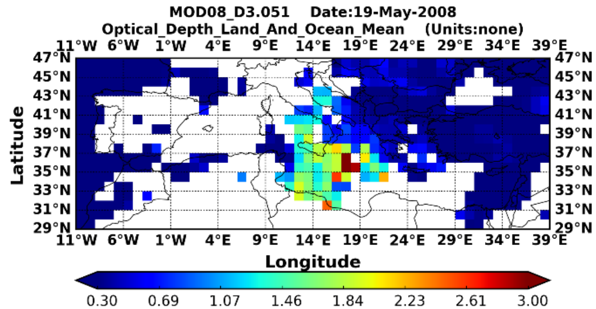
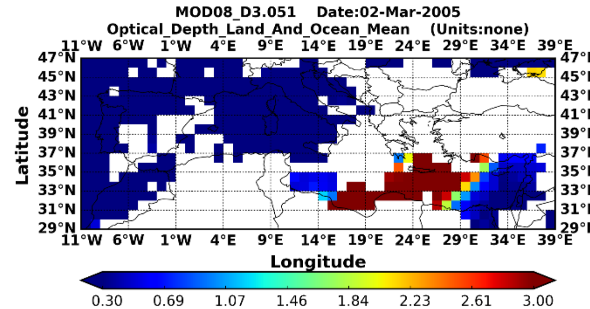
2 August 2012 | 19 May 2008 | 2 March 2005

MODIS-Terra (AOD@550)

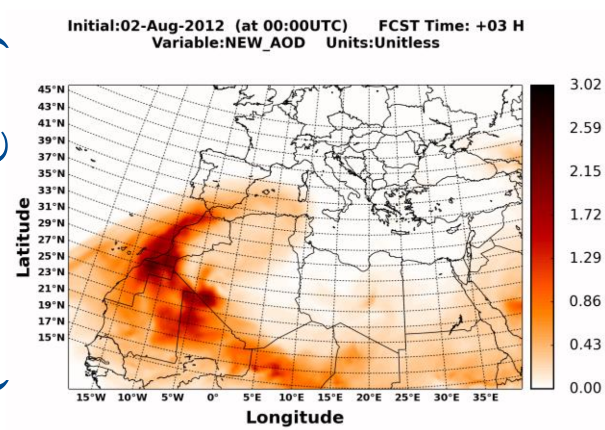


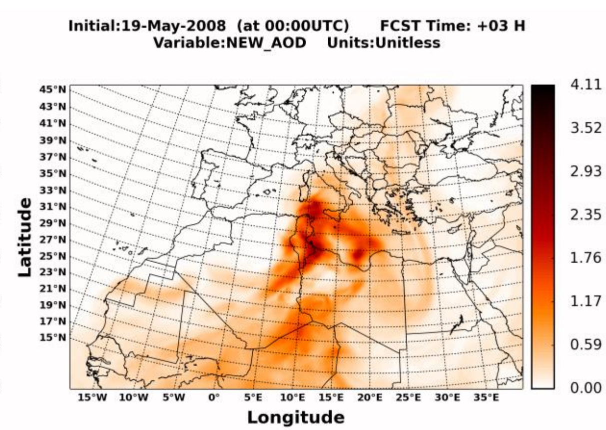


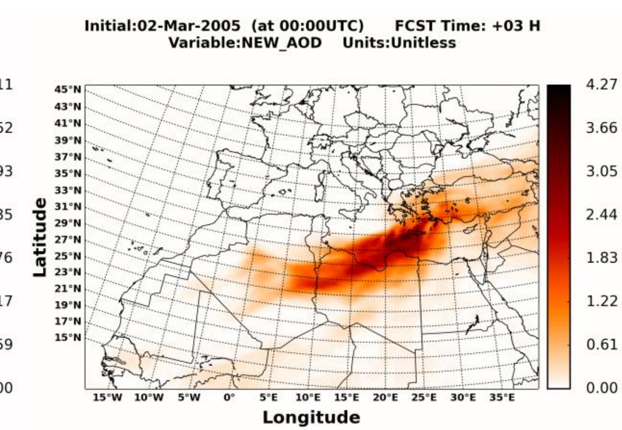


Satellite observations of the desert dust outbreaks

NMMB (Dust AOD@550)







NMMB short-term (84 hours) regional simulations initialized at 00 UTC of the desert dust outbreak day

Direct Radiative Effects (DREs)

Top of Atmosphere (TOA)

$$DRE_{TOA} = F^{\uparrow}_{TOA,RADOFF} - F^{\uparrow}_{TOA,RADON}$$

Downwelling radiation at surface (SURF)

$$DRE_{SURF} = F^{\downarrow}_{SURF,RADON} - F^{\downarrow}_{SURF,RADOFF}$$

Absorbed radiation at surface (NETSURF)

$$DRE_{NETSURF} = F_{NETSURF,RADON} - F_{NETSURF,RADOFF}$$

Into the Atmosphere (ATM)

$$DRE_{ATM} = DRE_{TOA} - DRE_{NETSURF}$$

- RADON/RADOFF: Activated/deactivated dust-radiation interactions
- Shortwave (*SW*), longwave (*LW*) and NET (*SW*+*LW*) radiation

Positive DREs indicate **warming effect** while **negative** DREs indicate **cooling effect**

Instantaneous NET DREs based on NMMB simulations (2nd August 2012)

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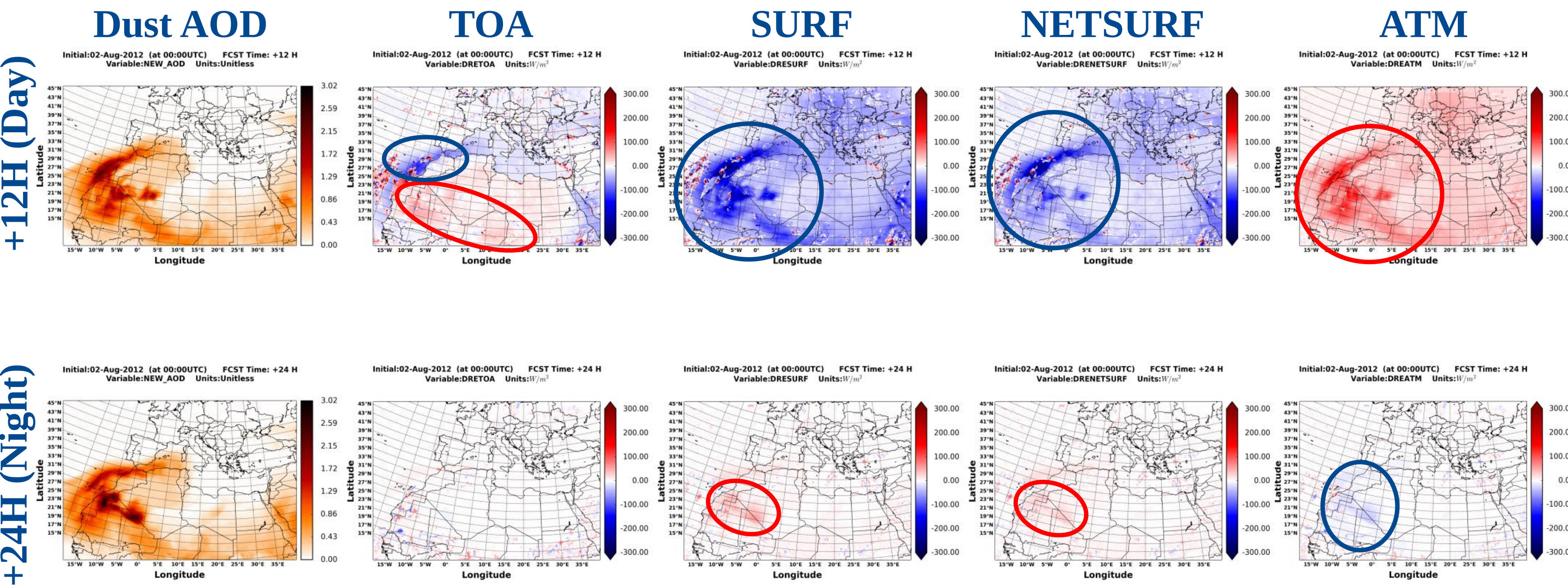

TOA
Warming/cooling
over desert/sea at noon
Higher/lower albedos

SURF & NETSURF
Cooling/warming
during day/night
SW/LW effects

ATM
Warming/cooling
during day/night
SW/LW effects

Strong impacts driven by the desert dust outbreaks' patterns

Regional DREs under clear sky conditions for the 20 desert dust outbreaks

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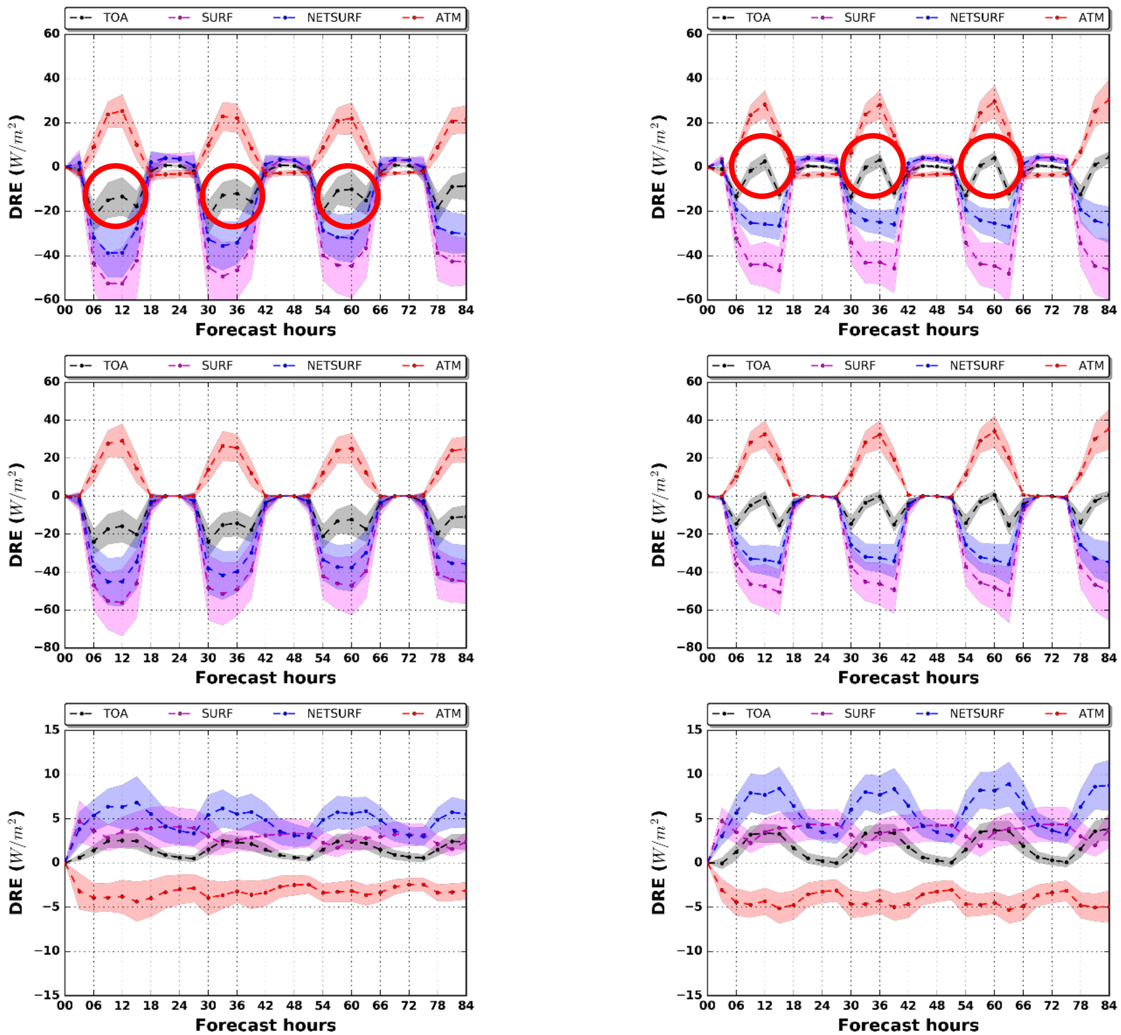
MSD | SDD

NET (SW+LW)
SW
LW



Surface **cooling** (up to 60 W/m^2)
Atmospheric **warming** (up to 30 W/m^2)
Planetary **cooling** (up to 20 W/m^2)

Slightly **higher** SW DREs compared to NET DREs

Reverse LW effects of **lower** magnitude compared to SW ones

Predominance of SW effects

- Planetary **warming** and **cooling** in SDD and MSD, respectively, at noon
- Higher albedos across the Sahara desert ➔ Increase of atmospheric **warming**

Impact on temperature at 2 meters: 2nd August 2012

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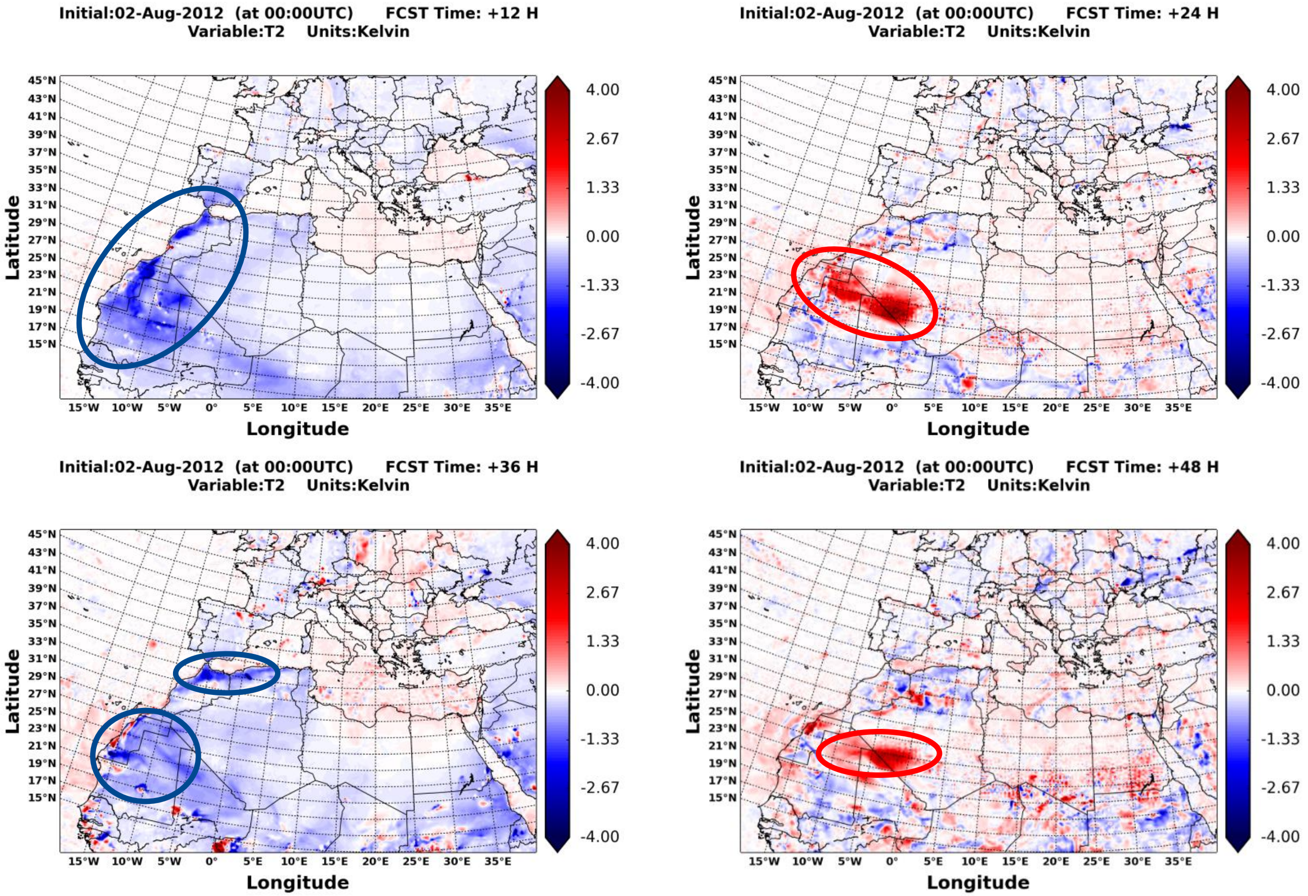
Daytime | Nighttime

+12H | +24H

+36H | +48H



- SW DREs ➔ **Reduction** of temperature at 2 meters (up to 4 ºC) during daytime
- LW DREs ➔ **Increase** of temperature at 2 meters (up to 3-4 ºC) during nighttime
- Reduction of the diurnal temperature range

Feedbacks on dust AOD and dust emissions (NSD)

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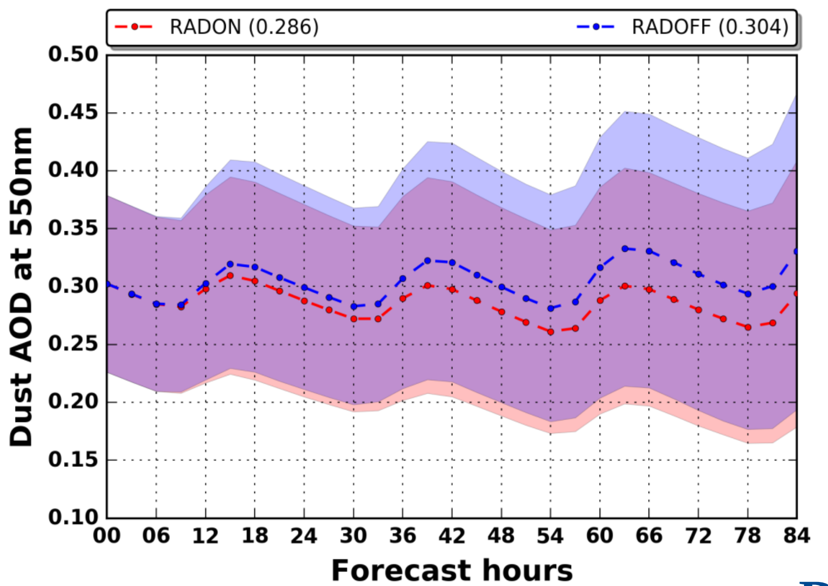
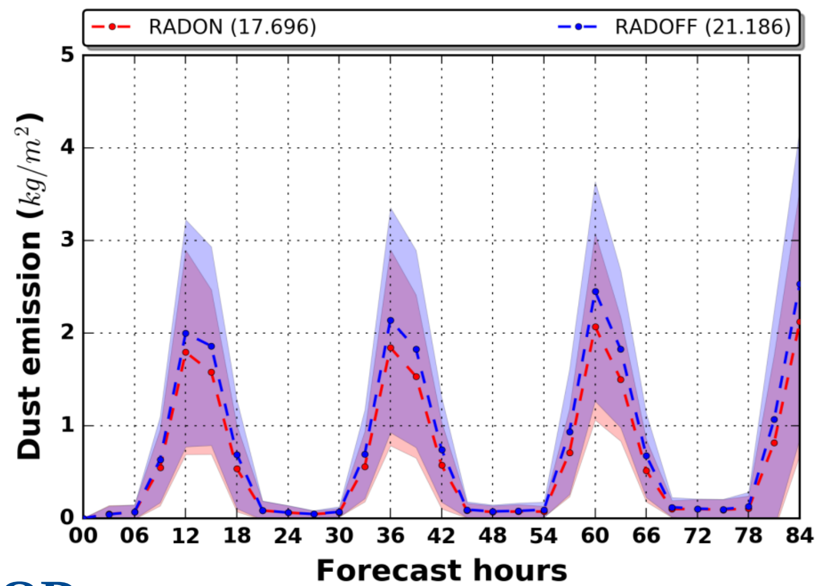
Dust AOD@550



Dust emission



Dust AOD

- Increasing RADOFF-RADON biases (**negative feedback**) for increasing forecast hours
- **Reduction by 6.3%** of the regional (NSD) dust AOD over the forecast cycle (84 hours)

Dust emission

- Reduction of dust emission at noon-late noon for the RADON simulation
- Reduced outgoing surface sensible heat flux from the ground
- **Reduction by 19.7%** of the regional (NSD) dust emission over the forecast cycle (84 hours)

Negative feedbacks on dust emission and dust AOD when dust radiative effects are considered into the numerical simulations

Downwelling SW and LW radiation: Comparison NMMB – BSRN

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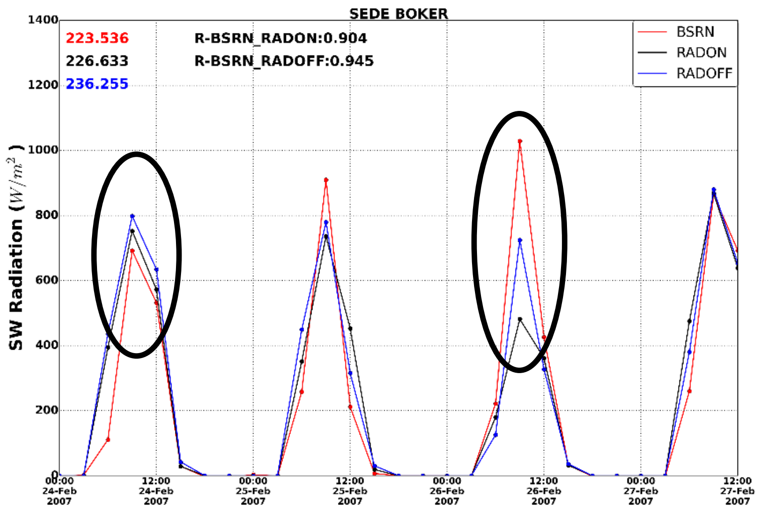
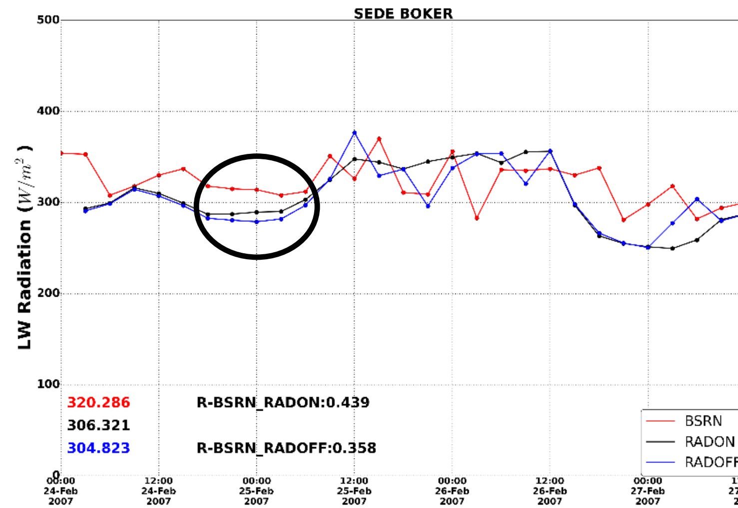
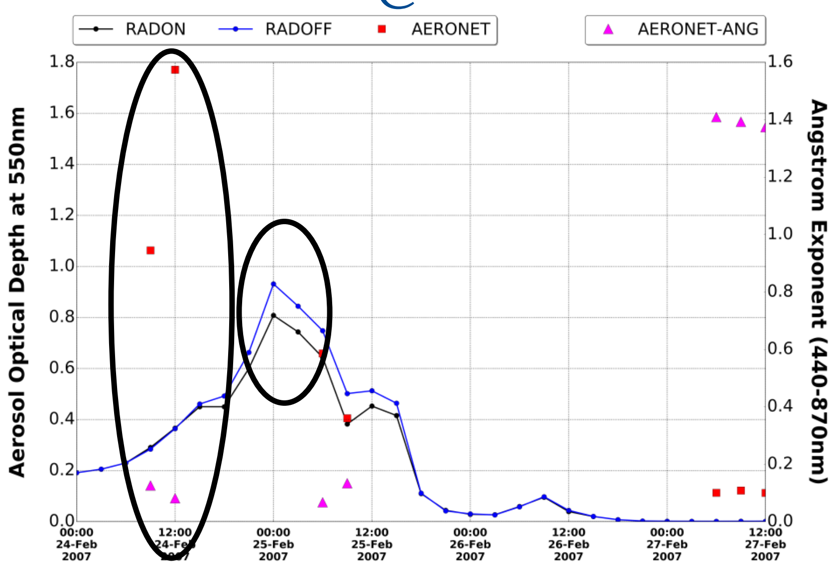
SW radiation



LW radiation



AOD@550nm



Sede Boker (Israel) | 24 Feb. 2007

- Misrepresentation of the dust outbreak by the model ➔ Overestimation (by 30-40 Wm^{-2}) of the SW radiation
- LW effect ➔ Reduction (by 20-30 Wm^{-2}) of the LW underestimation by the model (RADON)
- Underestimation (by 300-600 Wm^{-2}) of the SW radiation by the model ➔ Development of low clouds based on model simulations

Reduction of NMMB-BSRN differences for the RADON simulation

Temperature vertical profiles: Comparison NMMB – FNL (NSD)

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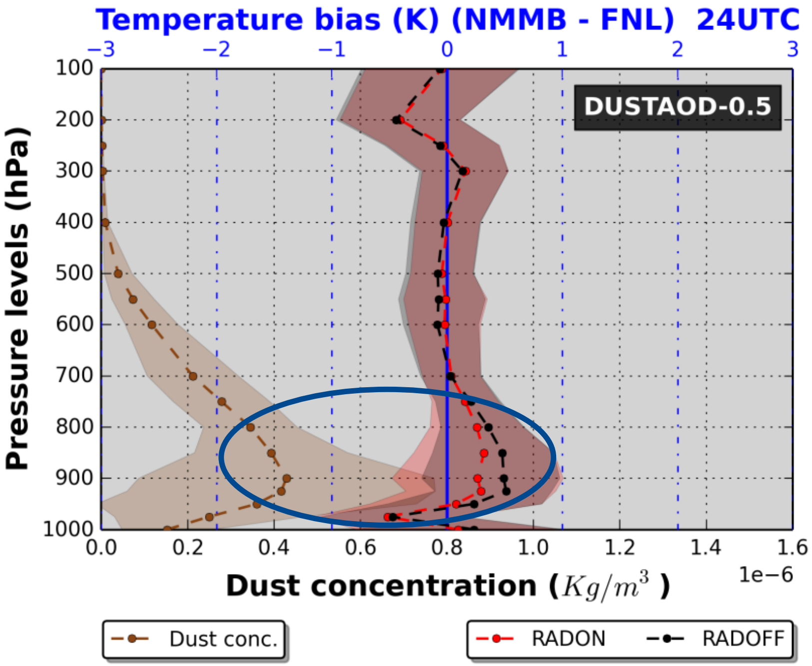
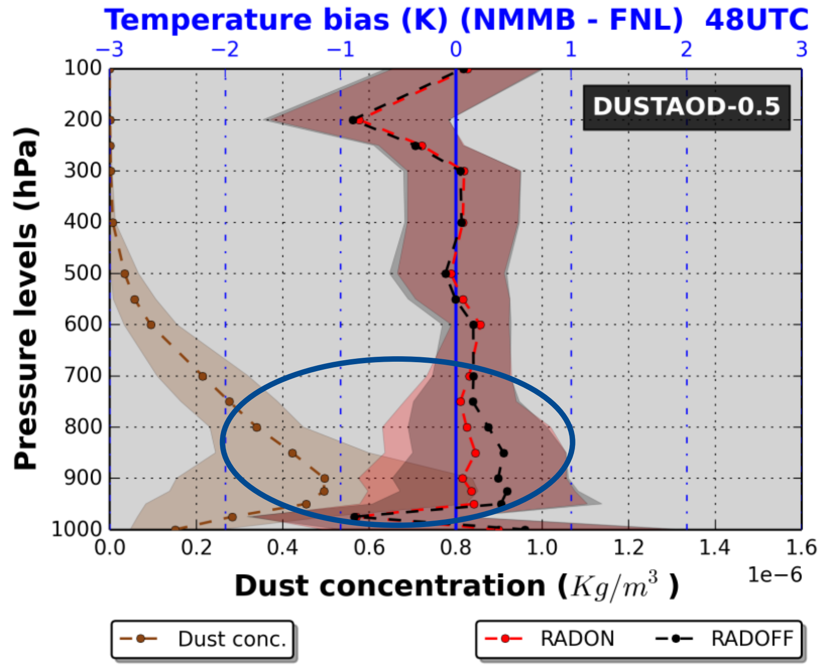
+24H



+48H



Dust AOD ≥ 0.5

LW effect → Reduction by 0.2-0.3 ºC, for the RADON simulation, of the model warm biases during nighttime

Conclusions

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- Identification of 20 intense and widespread Mediterranean dust outbreaks based on an objective and dynamic satellite algorithm
- Calculation of the instantaneous DREs based on short-term (84 hours) simulations of the NMMB/BSC-Dust regional model
  - TOA: **Cooling (up to 250 Wm^{-2})**/**warming (up to 50 Wm^{-2})** over sea/desert at noon ➔ higher albedos across desert areas
  - SURF & NETSURF: **Cooling (up to 300 Wm^{-2})**/**warming (up to 50 Wm^{-2})** during daytime/nighttime ➔ SW/LW effect
  - ATM: **Warming (up to 200 Wm^{-2})**/**cooling (up to 50 Wm^{-2})** during daytime/nighttime ➔ SW/LW effect
  - Predominance of the SW effects
- **Reduction**/**increase** of temperature at 2 m (by up to 4 °C) during daytime/nighttime
- **Negative feedbacks** on dust AOD and emission
- Reduction of the NMMB-BSRN biases, for the downwelling SW and LW radiation, when dust-radiation interactions are activated (RADON simulation)
- Better representation of the temperature fields during nighttime when dust radiative effects are considered into the numerical simulations (RADON simulation)

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